APPLICATION OF DMAIC FOR REFINING EFFLUENT RESULTS IN SEWAGE TREATMENT PLANT BASED ON SEQUENTIAL BATCH REACTOR TECHNOLOGY DURING STABLISATION PERIOD : A CASE STUDY

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Abstract

Environment pollution potential of city sewage with the advent of fast urbanization and better living standards is proving to be a big menace. Almost every city is facing problem of proper waste treatment and disposal. City sewage contains waste water generated from domestic activity and in addition, from the commercial, institutional and industrial units. These wastes besides having organic matter have other contaminants such as Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Selenium, Zinc, Chlorides, Sodium, Ammoniac Nitrogen, Radioactive Materials etc. If not properly treated these may cause various environment and health problems such as spreading of diseases, anesthetic look to receiving water bodies, kitting of aquatic floura and fauna etc. Hence proper treatment is required to be given to a city sewage before its disposal to any receiving system via land and water bodies. Conventionally it is done by providing following network of different treatment units. The present study is an attempt on understanding of working efficiency of an SBR Technology based Sewage Treatment Plant near 3 BRD, Chandigarh. The newly constructed Sewage Treatment Plant is solely based on SBR technology for biological treatment of City Sewage, which is fully automated and has PLC (Programmable Logic Control) System installed.

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Introduction

The city of Chandigarh has a well planned underground network of pipes for the disposal of sewerage generated in the city. It is obligatory for every residential/ no residential area. The sewerage system of the city has been designed by taking into account the natural slope of the city, which is from north to south. The sewage of the city flows under gravity in various pipes of different diameter ranging from 6” to 18” S.W. pipes and 24”X36” to 66” dia circular brick sewer. The total length of the sewer lines in the city is 1056 Km. The sewage is carried to a site in the south of the city where a plant has been constructed for its treatment and the treated sewage is than disposed off in an open Nallah. There are few pockets in the city which are at lower level and thus the sewage of these pockets cannot be discharged under gravity into the sewerage system of the city. The sewage of these pockets is pumped into the sewerage system and thereafter it flows under gravity to the Sewage Treatment Plant.

The unit processes of the SBR and conventional activated sludge systems are the same. A 1983 U.S. EPA report, summarized this by stating that “the SBR is no more than an activated sludge system which operates in time rather than in space.” The difference between the two technologies is that the SBR performs equalization, biological treatment, and secondary clarification in a single tank using a timed control sequence. This type of reactor does, in some cases, also perform primary clarification. In a conventional activated sludge system, these unit processes would be accomplished by using separate tanks.

Out of the various technologies, SBR Technology is the latest technology in practice these days. The need attracts such project which finally contributes in the schemes for the welfare of community. Deploying Six Sigma to such project is the beauty and uniqueness of the project.

The desired BOD level has been achieved by the new Sewage Treatment Plant but the conceptually there is a potential in the process to achieve the optimum desired level and there may be no requirement for the Tertiary Level Treatment. The Stablisation of newly constructed Sewage Treatment Plants is a difficult task in countries like India. This is due to the fact that sewerage generated in India, do have many unpredictable characteristics because of unawareness among the users and non availability of forceful laws in most of the segments of the country. People engaged in this area of work are always unheard due to their nature of job, where as there is a lot of scope for research on daily practices of Sewage workers. This thesis deals in application of Quality tools for improving the results of treated effluent to the standards that too BOD below 5 mg/l. For carrying out the detailed study, a State of the Art Technology based Sewage Treatment Plant has been selected near 3 BRD Air Force Station Chandigarh which is under stabilisation at present. This S. T. Plant is being maintained by Municipal Corporation Chandigarh. During the preliminary study it was observed that the results of two basins provided were stable but other two were not meeting the desired results. A complete quality Journey has to be implemented using the DMAIC (Define, Measure, Analyse, Improve & Control) concept for defining the problem to holding the gains by stabilizing these results.

Need :-

As BOD level required for the open disposal in the area needs to be less than or equal to 30 mg/ltr, whereas the technology has been designed for 10 mg/ltr for the influent. The Idea generated with the scenario that Chandigarh Municipal Corporation is utilizing its waste water for irrigation purpose after treating the Sewage Water up to Tertiary level and ensuring its BOD level less than 5 mg/ltr. The idea arises with the technologies flexibility with MLSS counts and its synchronization with DO sensors after achieving the optimum level. The BOD level can be achieved upto 5 mg/ltr by applying Six Sigma Concept and the Sewage Treatment Plant can be converted into zero discharge based.

There are only few technical parameters which effect the process control, where as there may be several other factors affecting efficiency of SBR. For example FM ratio, SVM, TDS, TSS etc. may also effect the working efficiency in some way or other. The efficiency dependence on the technical parameters involved can be easily calculated, whereas other factors need statistical approach in their analysis for finding their impact on plant efficiency. Such factors including technical parameters can be studied and a more rational way by applying principle of DMAIC. DMAIC is a six sigma concept and has been used in manufacturing as well as in service sector. This same concept has been used for refining the results of treated effluent in the existing treatment plant.

OBJECTIVES OF STUDY:

The present study has been conducted on existing treatment plant which includes following objectives:

- Daily analysis of incoming BOD, MLSS
- Daily Effluent BOD & COD
- Temperature Effect on effluent BOD
- TSS effect on effluent BOD

Application of DMAIC for achieving best efficiency in the existing plant.

SBR CYCLIC ACTIVATED SLUDGE TECHNOLOGY

Simply, state-of-the-art activated sludge treatment custom designed for the STP application. It is basically an energy optimizing process which operate to a very high performances standard which combines an admixture reaction zone with an integral fed-batch reactor operator under cyclic repletition.

Typical Cycle

For domestic sewage a typical nominal dry weather cycle will consist of 1-2 hours for fill-aeration 1 hour for settle and 1 hour for settle decant.

Fill-Aeration sequences

This is self-explanatory and refers to the process loading time in the cycle. Loading time in the cycle. Loading occurs outside of the designated settle and decant sequences during which time influent is received into the basin through an admixture (selector) reactor. Biomass from the main aeration zone is as mixed with influent load in the biological selector hydrolysis reactor. Complete-mix reaction conditions prevail in the main reaction zone during this variable volume operational sequence, being typical of a fed-batch reactor operation. Aeration can be regulated to maximize co-current nitrification-denitrification that takes place and to insure the aerobic uptake of phosphorous previously released during anaerobic operation. Fill sequencing is used to predominantly accumulate organic carbon substrate.

The process typically employs a nominally constant rate of recycle from the main reaction zone extreme from the inlet zone that is pumped to a zone at the inlet end of the admixture reactor.

Aeration sequences

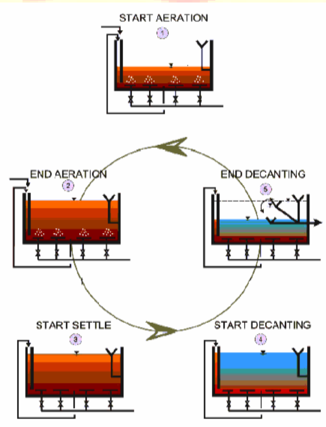
The aeration is still on but influent to the reactor basin is stopped. Complete-mix reaction conditions prevail in the main reaction zone during this operational sequence is used to increase the aerobic sludge age for efficient pollutant removal.

Settle sequence

The air is turned off and influent to the reactor basin is stopped (if not stopped before in the aerated sequence). During the first five minutes of this sequence, the residual mixing energy within the reaction basin is consumed. At this time gentle bioflocculation initially takes place, a solids-liquids interface forms under partial hindered settling conditions. Rising sludge does not occur.

Effluent withdrawal by Decanting

This sequence is an extension of the settle sequence and is totally quiescent whereby a moving weir lowering decanter is used to take the operating liquid level in the basin to its designated bottom water level reference position. In this way supernatant is withdrawn from a



subsurface position under laminar flow conditions. This allows optimum removal over the decant depth without entertainment of settled solids or floating debris. Upon completion of the supernatant liquid removal sequence, the moving weir decanter returns to its out of liquid rest position. Completion of the decant sequence terminates the designated use of the basin as a stratified, interrupted inflow reactor. Typically, sequencing begins while the decanter is travelling to its upper rest position.

METHODOLOGY

To start a quality journey with the available resources, a six sigma approach was chosen, though it need great set of culture but formulation part of the whole DMAIC program is attractive and empowers to design a project up to the last achievement. DMAIC is the most popular model of Six Sigma. The focus is on improvement of processes and solving problems. Process Six Sigma projects go through five phases:-

1. Define what needs to be improved.
2. Measure current performance and the gap with respect to desired target.
3. Analyze the process to find the root cause of the problem.
4. Improve Select a solution and implement.
5. Control the process parameters to assure and sustain improvement.

On the basis of above the problem at site was defined, as the average BOD of the treated effluent of the Sewage Treatment Plant near 3 BRD was coming above 10 mg/l during the stabilization period. Where as per the norms fixed by the Pollution Control Board this value should be less than 30 mg/l. The samples are passing the minimum norms kept by the regulatory agency but are failing to meet minimum standards of 5 BOD level for achieving tertiary level that too by adding no chemicals. For the result verification a third party was selected to check and verify the results.

To curb the problem of inconsistent results of BOD, the methodology been used as “DMAIC” and after the establishment of required results. The concepts of PDCA with available tool has been enforced in the research.

Chandigarh is the only city which earns its 70% of the revenue helping the govt. to plan its funds in darker zones. It is assumed that total 80% of the quantum of water supply comes out as Sewage. At present the total water supply of Chandigarh is 84.0 MGD (Million Gallon Per Day). Since the total generated sewer is assumed to be 67.20 MGD whereas city has potentials to treat 66.25 MGD. Chandigarh is a sole city in India which is having a potential to treat 100% of its generated sewer. But the challenge before the departments engaged in Operation and Maintenance of Sewerage Treatment Plants is to achieve high quality of treated effluent that can meet pollution control norms in low budget.

For this purpose Quality Tools shall be used to stabilize the results with systematic approach based on the physics of failure. It imparts an understanding of how, why and when to use the wide variety of Quality tools.

Chandigarh is a modern city with the view to provide best services to the citizens. As the city is a capital of two leading states of India and a hub of many administrators, technocrats and high profile residents, the service level requirements are very high. To meet the requirement of basic amenities like sewerage disposal system among the resident is "must achieve at optimum level". Hence to meet the above, system need full proofing. The system is having various components like source, machinery, pipes, valves etc. To meet the 100% expectations, achievable quality effluent of a system also need to be around 100%. As there are numerous Sewage Treatment Plants in the study. The STP selected is based on state of the art technology and need to get stablised at the earliest.

For the effective approach of Quality Journey in the waste water management sector, DMAIC approach was selected due to following :-

1) Poor quality of treated effluent can result hefty penalties from the pollution control board, environment loss, lost man hours due to sample failure and excess complaints.

2) An incapable process can produce bad results which require either excessive polishing or need to be byepassed in an open channel. Not conforming to the norms is a direct loss to the state and adversely affect the surrounding. Moreover, processes with poor capabilities result in inventories as a cushion for the low predictability. Moreover, processes with poor capabilities result in inventories as a cushion for the low predictability. Six sigma tools such as Multi-vari

(MV) charts, Anova, designed experiments, regression, can be very effective in pin pointing causes of variation so that we can reduce it.

3) Time taken and capital investment to implement engineering changes and database updating can be a major hurdle when it comes to opt new technologies in waste water treatment. Lean tools such as value stream mapping can be used to identify non-value-added steps in the process so that we can minimize or eliminate these to reduce process time.

As a service organization (Municipal Corporation Chandigarh) can have either insufficient and untrained staff. The online support system may not provide quick and easy navigation to solve problems in the working of S T Plant as the technique used is conventional and do not allow the systems like PLC/SCADA. Due to non functioning of some components of Sewage Treatment Plant, the results of treated effluent may give arise to the dissatisfaction among the pollution control agencies. Lean sigma can help in detecting the problems and stabilizing the results.

APPLICATION OF DIMAIC PLANNING

To start a quality journey with the available resources, a six sigma approach was chosen, though it need great set of culture but formulation part of the whole DMAIC program is attractive and empowers to design a project up to the last achievement. DMAIC is the most popular model of six sigma. The focus is on improvement of processes and solving problems. Process Six Sigma projects go through five phases:-

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On the basis of above the problem at site was defined, as the average BOD of the treated effluent of the Sewage Treatment Plant near 3 BRD was coming above 10 mg/l. Where as per the conditions laid for the recycling of effluent by the Municipal Corporation Chandigarh this value should be less than 5 mg/l. For the result verification a third party has been selected to check and verify the results.

BRAIN STORMING

Brain storming is a quality tool in which a meeting is organized to get number of probable causes of the problem. The number of stakeholders of the process despite of their ranks and designation are made part of the meeting. Every idea/reason suggested by each stakeholder is listed out. Each idea is given a due respect. Number of ideas generated may cause redundancy but the ideas must be noted down so that to hit vital few. In the study following ideas were generated

1. Raw Sewage quality.
2. Lack of Time Study.
3. Lack of Training.
4. In adequate Operator skill.
5. Incapable measuring system.
6. In adequate cleaning of screens.
7. In sufficient valve operation.
8. Less DO in the effluent.
9. Lack of awareness among sewerage workers
10. Insufficient cleaning of reactors.
11. Blower Shutdown.
12. Insufficient Aeration.
13. Non scheduling of Blowers.
14. Toxic Influent.
15. Non Functioning of Flow Meters
16. Synchronization between Auto and Manual
17. Less Bio-Culture.
18. Less MLSS Counts.

21. Temperature variations.
22. Less Sludge Volume.
23. Rainy Day.
24. Excess influent.
25. Uneven distribution of air.
26. Septic Conditions.

27. Scum formation.
28. Trash filming.
29. Scum deposition on sensors.
30. Faulty level sensors.
31. Faulty DO Sensors.

Short listed Probable Causes

1. Raw Sewage Quality.
2. Mixing of Untreated Industrial Sewage
3. Lack of training.
4. Septic conditions in reactor/aeration tank.
5. Inadequate Operator skill.
6. Less MLSS Counts.
7. Lack of maintenance of outlet valves.
8. Insufficient grit removal.

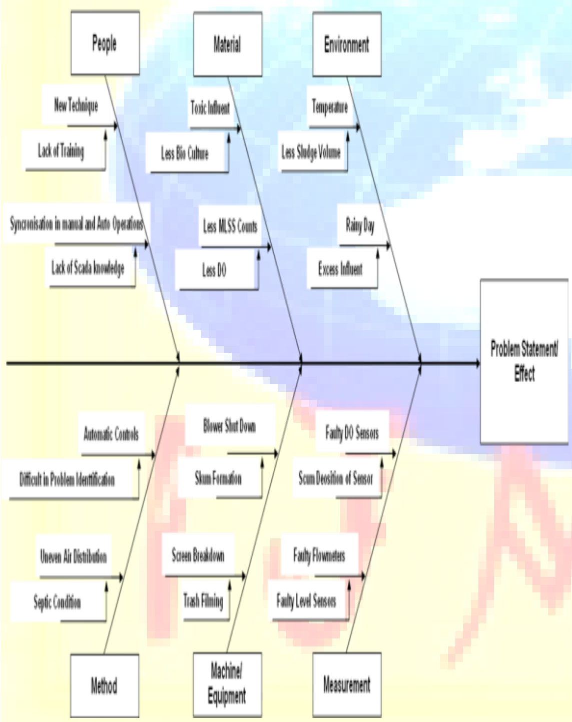
Tracking the Process before Treatment Process following Observations was Noticed:-

1. Colour difference
2. Instant pH value less than 7.
3. Difference in BOD reduction.
4. DO and 5 day BOD
5. Control Charts were drawn.

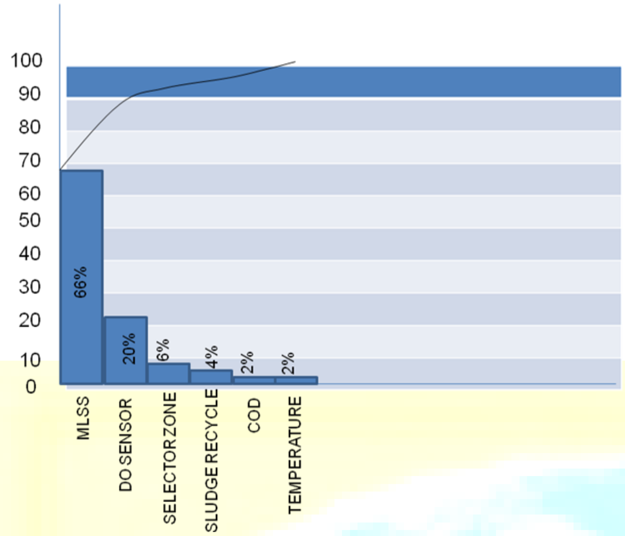
CAUSE AND EFFECT DIAGRAMS

The cause & effect diagram is the brainchild of Kaoru Ishikawa, who pioneered quality management processes in the Kawasaki shipyards and in the process, became one of the founding fathers of modern management. The cause and effect diagram is used to explore all the potential or real causes (or inputs) that result in a single effect (or output). Causes are arranged according to their level of importance or detail, resulting in a depiction of relationships and hierarchy of events. This can help you search for root causes, identify areas where there may be problems, and compare the relative importance of different causes. The C&E diagram is also known as the fishbone diagram because it was drawn to resemble the skeleton of a fish, with the main causal categories drawn as "bones" attached to the spine of the fish. Cause & effect diagrams can also be drawn as tree diagrams, resembling a tree turned on its side. From a single outcome or trunk, branches extend that represent major categories of inputs or causes that create that single outcome. These large branches then lead to smaller and smaller branches of causes all the way down to twigs at the ends. The tree structure has an advantage over the fishbone-style diagram. As a fishbone diagram becomes more and more complex, it becomes difficult to find and compare items that are the same distance from the effect because they are dispersed over the diagram. With the tree structure, all items on the same causal level are aligned vertically. Similarly in our study the objective to find out the root cause of the effluent a Fish Bone Diagram has been prepared to analyse the root of the problem.

Cause and effect diagram showing Root Cause Analysis of the Problem

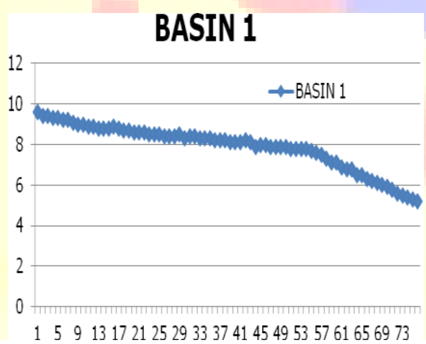


Pareto chart showing various causes of failure at SBR Reactors



RUN CHARTS

Run chart has been prepared on the basis of working of Reactors of SBR, analyzing their results on routine basis. The attributes which are crucial in BOD value has been targeted and a statistical data reveals that there is a close relation between MLSS counts of the reactor and BOD fluctuation. The biggest constraint in the study was practically found was MLSS Count results can be calculated on same day but the BOD results would take 3 to 5 days as per the standard procedures.



RUN CHART – 1 FOR BOD OF BASIN 1

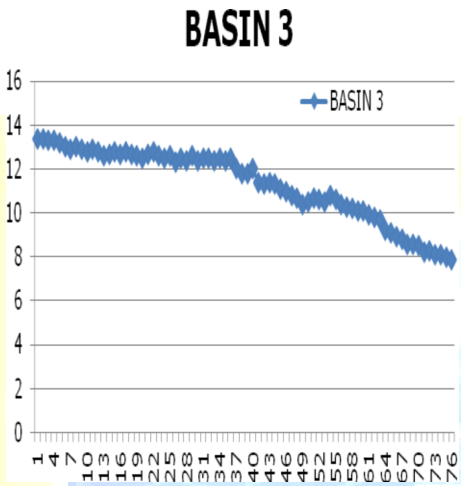
Observations from 1st June 2013 to 15th August 2013

1. The trend of BOD readings after Basin-I shows that BOD has decreased from 10 mg/ltr to 5 mg/l in a span of 76 days.
2. The trend shows corresponding values to the MLSS Counts.

Observations from 1st June 2013 to 15th Aug2013

1. The trend of BOD readings after Basin-II shows that BOD has decreased from 10 mg/ltr to 5 mg/l in a span of 76 days.

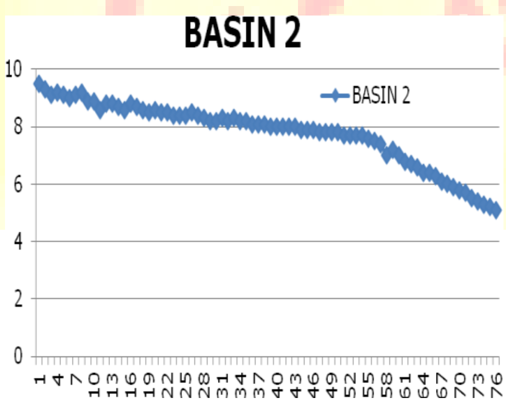
2. The trend shows corresponding values to the MLSS Counts.



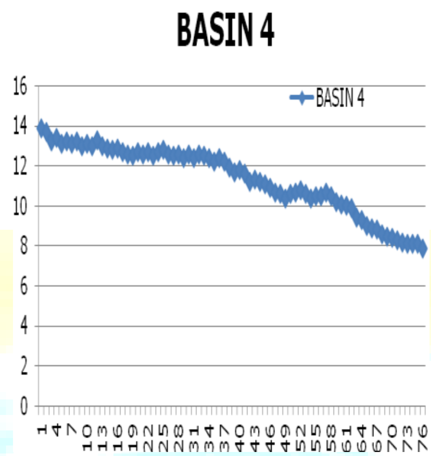
RUN CHART – 3 FOR BOD OF BASIN 3

1. The trend of BOD readings after Basin-III shows that BOD was touching 13 mg/ltr, has decreased from 13 mg/ltr to 8 mg/l in a span of 76 days.

2. The trend shows corresponding values to the MLSS Counts. MLSS counts bserved were less than Basin I and Basin II.



RUN CHART – 4 FOR BOD OF BASIN4

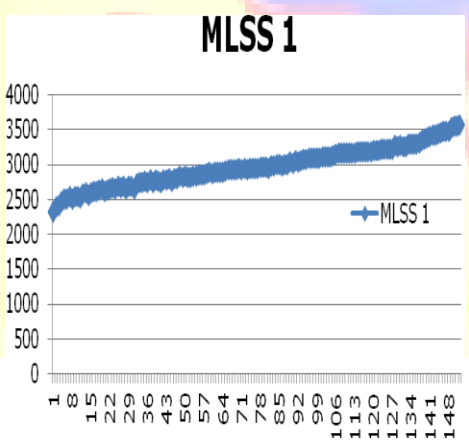


Observations from 1st June 2013 to 15th August 2013

1. The trend of BOD readings after Basin-III shows that BOD was touching 14 mg/ltr, has decreased from 13 mg/ltr to 8 mg/l in a span of 76 days.

2. The trend shows corresponding values to the MLSS Counts. MLSS counts observed were less than Basin I and Basin II.

RUN CHARTS OF MLSS COUNTS

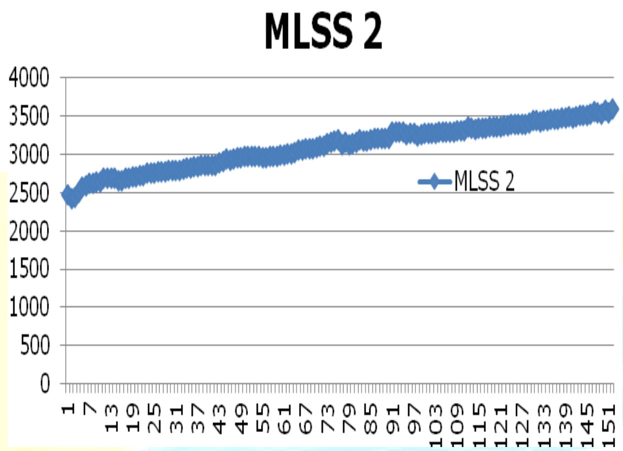


SHOWING RUN CHART FOR MLSS COUNT RANGE THROUGH OUT THE DMAIC JOURNY OF BASIN 1

Observations

1. The trend of MLSS counts is inversely proportional to BOD, as the MLSS increases, the BOD decreases.

2. The trend shows corresponding values to the Raw sewage BOD.

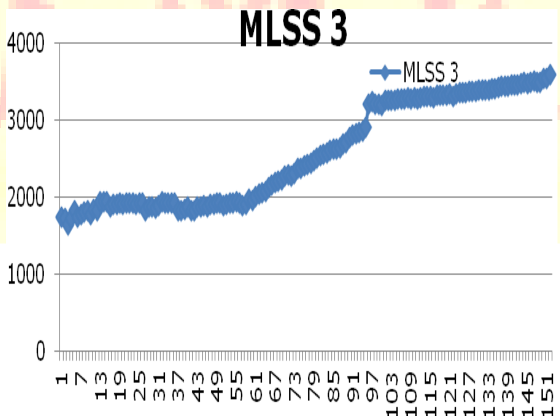


SHOWING RUN CHART FOR MLSS COUNT RANGE THROUGH OUT THE DMAIC JOURNY OF BASIN 2

Observations

1. The trend of MLSS counts is inversely proportional to BOD, as the MLSS increases, the BOD decreases.

2. The trend shows corresponding values to the Raw sewage BOD.

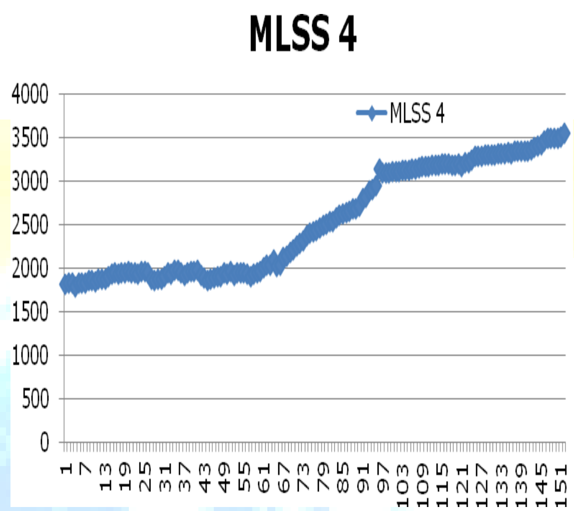


SHOWING RUN CHART FOR MLSS COUNT RANGE THROUGH OUT THE DMAIC JOURNY OF BASIN 3

Observations

1. The trend of MLSS counts is inversely proportional to BOD, as the MLSS increases, the BOD decreases.

2. The trend shows corresponding values to the Raw sewage BOD.



SHOWING RUN CHART FOR MLSS COUNT RANGE THROUGH OUT THE DMAIC JOURNY OF BASIN 4

Observations

1. The trend of MLSS counts is inversely proportional to BOD, as the MLSS increases, the BOD decreases.

2. The trend shows corresponding values to the raw sewage BOD.

3. Overall MLSS values do have fluctuation but Bio Culture shoots up in no time even during acidic attacks in influent.

ROOT CAUSES ANALYSIS

1. The reduction of BOD in Basin III and Basin IV is small whereas Basin I and Basin II are showing improved results.

2. This improvement in results in Basin I and II may be due to the fact that more recycled sludge was added to the tank thus increasing MLSS concentration in these tanks.

COUNTER MEASURE

1. Adding sludge continuously in the reactor using additional submersible pumps for increasing MLSS counts.
2. Effectiveness of Inprocess Gauging System like DO Sensors etc. to be ensured.

ALTERNATE SOLUTIONS AVAILABLE

1. Less raw sewage to be lifted from the inlet .
2. Inspecting & making new SOPs.
3. Adding PLC only to overcome faults due to Man and Machine errors.
4. Upgrading the medium of data transfer.
5. By adding chemicals for coagulation and for disinfection.

ACTION PLAN

1. Inspection of Reactors after desludging.
2. Inspection of Blower and Valves.
3. Inspection of gates.
4. Inspection of Air Distribution Grid.
5. Desludging of Reactors.
6. Inspection of Decanters.
7. Proper gauging at Inlet, Outlet and after reactor.
8. Time study for retention period.
9. Training of Operators.

ACTIONS TAKEN

1. Desludging of Reactors and refilling of sludge.
2. Gauging pressure from blower to outlet.
3. Constant check with PLC of Primary and Secondary Unit.
4. Time study on worker and change in SOPs.
5. Daily Check list.
6. Removing trash from screens.

ACTIONS EFFECTIVENESS

1. Repeat sludge accumulation in the splitter zone helped in improving MLSS Count.
2. Improvement in DO percentile.
3. Operators and Sewermen found themselves as process owner and machine owner.
4. Automatic level switch helped in avoiding septic conditions inlet sump.
5. Instant DO meters helped in estimating BOD at any Particular time.
6. Continuous mixing of sludge helped in estimating MLSS counts.
7. Most of the rejected samples were found in the third and fourth reactor.

GAINS OBTAINED

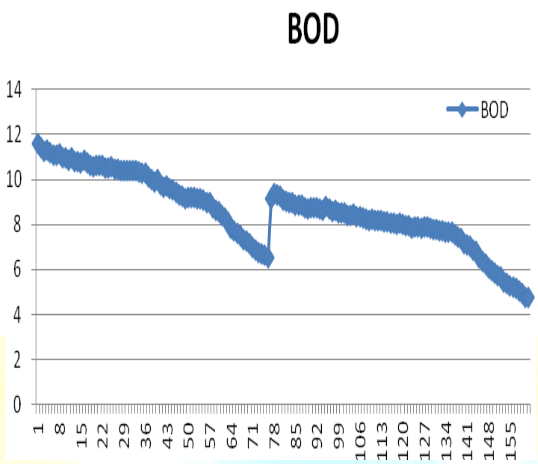
1. Consistency in results, BOD coming less than 5 mg/ltr.
2. Tertiary level Treatment not adding additional chemicals.
3. Reliability on Reactor III and Reactor IV got improved by upgrading the Monitoring System.
4. Benchmarks for MLSS Counts obtained.

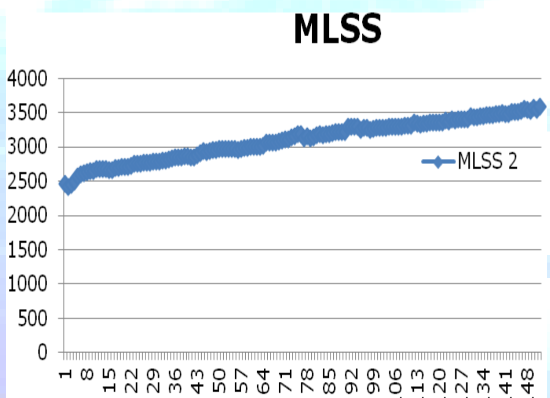
STANDARDIZATION

1. Amended the Control Plans and Operation standards for SBR Reactors and SCADA Unit.
2. Standards for Setup Approval were modified as per new Method requirements.
3. Delegation of powers, graduating an operator to work as owner of the component.
4. Separate team was trained for immediate remedy on getting the results deteriorated.

SUMMARIZING THE DATA

With the help of Pareto analysis, it is possible to identify three main defects which conclude for 80% of total defects. We applied DMAIC methodology on two of our main defects in order to identify the reasons.





As per the above compression it is concluded as under

1. The trend of MLSS counts is inversely proportional to BOD, as the MLSS increases, the BOD decreases.

2. The trend shows corresponding values to the raw sewage BOD.

CONCLUSIONS

1. On the basis of results obtained in terms of BOD reduction in the SBR and after applying the concept of DMAIC in the process control of BOD reduction, It can be concluded from the study that there was a strong relation between MLSS counts and BOD. When MLSS counts were maintained between 4400 mg/l to 4600 mg/l, the BOD_5 results varied between 4 mg/l to 5 mg/l. Thus as good as 5 mg/l, BOD_5 can be achieved by avoiding chemical addition in SBR treatment.

2. The applications of DMAIC are easy to be established in the units like Sewage Treatment Plants where the process is defined and sub-processes can be controlled by using data available. The BOD results improved from 10 mg/ltr to 5 mg/ltr, by identifying the problem and improving it in a DMAIC format of problem solving.

3. Tertiary level treatment can be achieved with less retention period in reactors which saves priceless energy. The retention period in the conventional ASP is 4-8 hrs. Here for complete SBR cycle i.e. feeding, aeration and sludge setting time is only 180 minutes. Out of this total time 90 minutes are taken in the aeration of sewerage. This means retention period of only 1.5 hours is needed which is appreciably less than retention time required in conventional ASP.

4. The study shows that using tools like Brainstorming is a boon to the Organisations involved in service Sectors especially government bodies. The hierarchy protocol leads to posing a wall between the workers and management. The practical ideas cannot become feedback leading to failure of high budget government schemes. In this case operators were also made as part of the Brainstorming session and this helped in giving useful ideas. However it was easy to assess the problems which were actually occurring in Basin III and Basin IV due to less MLSS counts during the stablisation period.

5. The study also revealed that overall MLSS values also have fluctuations depending upon the Influent Bio Culture in SBR Reactor which is directly affected with the acidic attacks in influent.

6. The depleting performance of the Reactor III and Reactor IV was encountered by adding sludge continuously in the reactor using additional submersible pumps for increasing MLSS Counts.

7. Some SOPs have been developed during the Implementation of DMAIC Applications, Those are now part and parcel of the routine maintenance and process management. These SOPs (Standard operating protocol) have been designed and embedded with quality concept. During the process, the results can be assessed by taking into account of MLSS and Instant DO Meters. Even though, in automatic mode the Operation can be handled after going through the lab

results. Basin I and Basin II responded to the desired level and BOD simultaneously started decreasing. It was easy doing Pareto Analysis to figure out the main problem.

8. Recycling the sludge from Basins to splitter zone for accumulating more active sludge to increase MLSS counts and Synchronizing the MLSS counts with DO sensor is another useful task to fix the protocol for Operation and maintenance of the STP.

9. Continuous monitoring of sewage quality not only raised the level of cleansing the effluent but also set the benchmarks to all the stakeholders of the process. Service sector specially catered to the public for providing basic amenities is mostly governed by government organization not in India but also in the rest of the world. The DMAIC applications can be implemented in the spirit of global quality service deliberation.

10. With monitoring of MLSS, the performance of the Reactor can also be assumed on daily basis, Level switches also contributed in equalising retention period for the various batches of the effluent.

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